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Mummy · Genetics · Soft tissue

Abstract
Ancient Egyptian human remains have been of interest in the fields of both medical and Egyptological research for decades. However, canopic jar holders for internal organs (liver, lungs, stomach, intestines) of Egyptian mummies appear to be but a very occasional source of data for such investigations. The few medical approaches focusing on the content of these jars are summarized and listed according to pathogens and diseases to give a structured overview of this field of study. An extensive search of the literature has been conducted from different bibliographic databases with a total of $n = 26$ studies found. The majority of diseases found consisted of infectious diseases and internal medicine conditions such as schistosomiasis or emphysema. These are just 2 examples of many that, instead of primarily affecting bone, muscle or skin, specifically target internal organs. Hence, a better understanding of the evolution of diseases that still affect mankind could be gained. In conclusion, this reassessment shows that canopic jars represent a highly underestimated source for histological, radiological and ancient DNA examination of Ancient Egyptian remains and should, thus, be more and more brought back into the focus of retrospective medical research.

Introduction

"Canopic jars" represent viscera containers of Ancient Egyptian mummies: because of their various forms and shapes they ought to be more appropriately referred to as "canopic equipment" [1]. During the 4th Dynasty (Old Kingdom, ca. 2600 BC), the first canopic containers and jars were developed, each containing a specific internal organ, namely, liver, lung, stomach and intestine [2]. During the 8th Dynasty, at the beginning of the First Intermediate Period (ca. 2200–2000 BC), the design developed into 4 jars with human heads, representing the 4 children of Horus. In the Ramesside Period of the New

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Kingdom (19th Dynasty, ca. 1300 BC), the heads changed to the iconic layout with one human head (Amset), a baboon (Hapy), a jackal (Duamutef) and a falcon (Qebekhsenuef). Even in the New Kingdom, when the tradition of using canopics reached a peak, following local traditions, bodies were mummified without removing the viscera or the brain, for example, Kha and Merit in Deir el-Medina (mid-18th Dynasty, ca. 1350 BC) [3]. The range of mummification methods is much broader than is generally believed [4]. The disappearance of the funerary practice of placing organs into canopic jars can be observed from the Roman Period (ca. 30 BC–350 AD) not only because of a lack of technical embalming skills but also on account of a new focus on the mummy portrait and elaborate wrapping. Thus mummies' viscera became gradually less important and were left in situ [1, 4, 5]. Since a great number of pathogens and diseases have their main localization in visceral body districts, preserved internal organs from Ancient Egypt can be considered to have significant medical interest. Radiological, histological as well as ancient DNA analysis of embalmed viscera may reasonably yield new information about the actual presence, phenotype and genotype of diseases in ancient times, thus leading to a better understanding of their evolution and historical trends [6, 7]. Compared to the high number of publications on mummies, only few approaches aimed at determining diseases in ancient internal organs have been produced. The purpose of this article is to offer an overview of pathogens and diseases found in canopic jars. The approach adopted here consists of reviewing the available literature on the topic by offering a detailed overview of the major pathological results obtained for biomedical research over the past decades. At the secondary level, this article endeavours to suggest novel approaches and highlight key scientific questions to be addressed by future palaeopathological and bioarchaeological research.

Material and Methods

An extensive online search was performed in the platforms PubMed, Google Scholar, ScienceDirect, and Rechercheportal (online library of the University of Zurich, Zurich, Switzerland) using the non-MESH terms "canopics," "canopic equipment," "canopic jars," complemented with more medically and biologically oriented entries such as "mummy" and "mummies." Furthermore, the terms "viscera," "remains," "soft tissue" and "internal organs" and more specifically "liver," "lungs," "stomach" and "intestines" were looked up in combination with the above-listed terms. The online search was enriched via a traditional research in conventional libraries (e.g., Zentralbibliothek and the Library of Egyptology, University of Zurich, Zurich, Switzerland) on the subjects of mummies and mummified internal organs. After gaining background information on the topic, the investigation started focusing on the different diseases reported in Ancient Egyptian human remains, which in turn yielded additional bibliographical references. One of the key criteria was finding references specifically and solely about Egyptian mummified bodies. This choice excluded all publications about mummies from other geographical locations. In later dynasties – besides extracorporeal canopic jars – intracorporeal embalmed viscera packages existed (i.e., left inside the emptied body cavity of the mummy): these embalming options have also been included in this study. As an additional methodological note, it should be remarked, that although the dramatic technological development makes the most recent publications of higher scientific value, the large quantity of much earlier publications, albeit drawing on not so advanced techniques, has equally proved of interest for the present assessment. Finally, in order to better contextualize the discussed pathologies, a historical search of their first recognized scientific description has been performed.

Results

$N = 26$ publications from 4 different databases were found to be matching the above listed criteria and were thus considered to be of interest for this research. The following results were presented according to the system affected by the pathological process, while parasitic infections have been grouped irrespective of the targeted organ or system.

Parasitic Infections

Schistosomiasis

This disease was first described by Theodor Bilharz (1825–1862) during an autopsy in 1851, hence its original eponym *bilharziosis* [8]. One of the investigators to focus on the rehydration of soft tissue samples from Egyptian mummies back to a status – despite the obvious limitations – comparable to the time before death was Marc A. Ruffer (1859–1917), the founder of modern palaeopathology. He was the first to describe calcified eggs of *Schistosoma haematobium* in Egyptian mummies [9]. The parasite infested the body via the intact skin or was ingested. Ruffer found the calcified eggs in the kidneys of 2 mummies of the 20th Dynasty. Later studies found eggs of *Schistosoma haematobium* in Egyptian mummies, such as the Royal Ontario Museum I mummy (ROM I), where not only eggs but also potential alterations in the hepatic architecture were observed [10]. Scientists conducting the autopsy of ROM I found schistosomal eggs penetrating the muscular layers of the small and large intestines, the bladder and also infestation of the portal areas combined with signs of early cirrhosis, thus suggesting fibrotic response as a result of an infection by *Schistosoma*.

They also found calcified eggs without terminal spines, which are typically for *S. mansoni* (another subspecies); therefore, they supposed that it could not be *S. haematobium*. Nonetheless, it is interesting to note that both forms are endemic in Egypt nowadays, and the possibility of a co-infection should be taken into account [11].

Leishmaniasis

These subspecies morphologically appear in 3 different forms: visceral, cutaneous and mucocutaneous when transmitted from sand flies (Phlebotomidae) to humans. It is believed that cutaneous forms were already mentioned in Ebers Papyrus (ca. 1550 BC), as "Nile Pimple." The cutaneous disease has long been long well known in the Arab world as well as in Africa, Central Asia and South America. Arab scientists had different names for the disease until 1885, when Cunningham first identified the parasite and Lühe named it *Leishmania tropica* in 1906, a name still used today. In 1911, Vianna attributed the recently discovered mucocutaneous disease in South American areas to a new species of the pathogen named *Leishmania braziliensis* [12]. In 1903, Ross was the first to introduce the term *Leishmania donovani* after the parasite was isolated at the same time by William Leishman and the Irish physician Charles Donovan, independently from one another [13]. Visceral leishmaniasis is of special interest to canopic jar research, since it affects internal organs like the liver, heart, spleen or kidneys. Zink et al. [14] found 4,000-year-old *L. donovani* DNA from bone tissue after amplification via PCR proving that visceral leishmaniasis was indeed present in Ancient Egypt. However, all the mummies affected with leishmaniasis came from the Middle Kingdom, and therefore no general statement about earlier and later periods could be made.

Cysticercosis

Filled vesicles of *Taenia* were first observed in the corpus callosum of a man died of a stroke by Domenico Paranolo in 1550 [15]. The first correct description of *T. solium* and *T. saginata* were made by Linnaeus [16] (1707–1778) in 1758 and Goeze [17] (1731–1793) in 1782 respectively. However, the disease cysticercosis was first discovered in pigs by Hartmann in 1688. The eggs of the 2 tapeworms *T. solium* or *T. saginata* may be similar in shape, but they are different in their clinical appearance. Reyman et al. [11] pointed out that during the investigation of Nakht (ROM I), whose intestinal tissue had been sampled, numerous eggs of *Taenia spp.* were found but they could not be further differentiated into *T. solium* and *T. saginata*. Bruschi et al. [18] were able to distinguish between the 2 forms of infection caused by the parasite. The mummy they investigated dated to the Ptolemaic period and was of young age at the time of death. The female individual was mummified and the organs were extracted, embalmed and put back into the body's cavity. The immunohistochemical analysis of a macroscopically visible cystic lesion of the stomach wall demonstrated the presence of *T. solium*.

Trichuris

One of the most common parasitic infections in the world is the infestation by *Trichuris trichiura*, especially where access to clean drinking water is scarce and general supply is poor. The first to locate these parasites in the caecum and transverse colon was Morgagni [19] (1682–1771) in 1740 followed by more precise morphological descriptions by Roederer [20] in 1761 and finally classified as nematode by Linnaeus [21] in 1771 [22]. The resulting disease is often asymptomatical, but it can exacerbate into haemorrhagic inflammation of the colon. Bouchet et al. [23] provided evidence of *Trichuris* eggs found in canopic jars from natural mummified individuals ranging from 2400 BC to 1500 AD suspecting that the infection occurred in Egypt due to the intensive trade with Nubians. The canopic jar containing the parasite's eggs are from the New Kingdom (18th–20th Dynasty) [24].

Ascaris

During the autopsy of PUM II (Pennsylvania University Mummy) by Cockburn et al. [25], a single egg of helminthic nature was detected in the intestinal tissue. After examining the specimen, the conclusion was that it was the roundworm *Ascaris*, most probably *A. lumbricoides* [25]. The parasite was anatomically described by Tyson [26] (1650–1708) in 1683 before Linnaeus [27] gave it its currently known name in 1758. A significant overview of the life cycle was given by Ransom and Foster [28]. The larvae of this parasite first infest the intestinal tract, and then migrate through the wall of the intestine to the liver, lungs and in a retrograde manner, via the trachea, again to the intestinal tract. This means that during the larval stage in humans, the parasite could be visible in lung, liver or stomach tissue and therefore, findings in canopic jars would not be surprising.

Respiratory System

Bronchopneumonia and Pulmonary Oedema

Hippocrates (460–377 BC) provided the first detailed definition of the disease although realistically it had already been known since long before. He introduced the term "peripneumonia" and described its symptoms [29]. In 1881, the bacterial pathogen *Streptococcus* pneumoni-

ae, found to be the causative agent of pneumonia, was isolated independently by Pasteur [30] (1822–1895) and Sternberg [31] (1838–1915). The definition of pulmonary oedema in a medical sense first emerged in 1819 when Laënnec described it as "an infiltration of serum into the pulmonary tissue, carried to a degree such that it significantly diminishes its permeability to air" [32, 33]. Looking at histological specimens of lung tissue, an exudate consisting of a mix of fibrin, protein and granulocytes can be clearly seen, whereas the structure/scaffold of the lung remains mostly intact. These findings were first reported in mummified lungs by Shaw [34] in 1938 and in subsequent investigations, such as that by Walker et al. [35] in 1987, showed bronchopneumonia with fibrinous or proteinaceous exudate despite the fact that the alveolar structure remained normal. Walker et al. [35] even suggested that in 2 of the 6 investigated lung tissue samples from embalmed viscera, the pneumonia and pulmonary oedema led to respiratory failure and subsequently to death. Shaw [34] examined the corpse and internal organs of the mummy of Har-mose (18th Dynasty, New Kingdom, ca. 1490 BC), in whose grave lay a wooden box placed at his feet, which contained the preserved viscera, namely, lung, liver with gall bladder, mesenterial and intestinal tissue. The researchers considered acute bronchopneumonia and pleurisy as the most probable cause of death. This was supported by a sample of the lower lobe of the lung stained with the van Gieson method, which led to the retrospective diagnosis of acute bronchopneumonia [35].

Emphysema

It was the French physician René Laënnec (1781–1826) who originally reported the pathology of pulmonary emphysema separately from chronic bronchitis and asthma in 1819 [36, 37]. A case of emphysema of the lungs was shown during the autopsy of the Egyptian mummy Harmose. The coffin, at the mummy's feet, contained viscera among which lungs, which were subjected to histological examination. Macroscopically, the 3 lobes of the right lung were well distinguishable and the middle lobe consisted of "emphysematous air sacs," as well as the anterior border of the lower lobe below the apex that contained a "subpleural emphysematous bulla" of the size of 0.5 cm. It was noted that the middle lobe was filled with so much air that it floated in water, whereas the lower lobe did not. The alveolar structure of the upper lobe was normal, while the alveolar walls of the middle lobe were weakened and thinned as a result of the abnormal condition of emphysema [35]. Another investigation on lung tissue from Ancient Egyptian mummies by Walker et al. [34] focused on the remains of Henutmehyt (19th Dynasty New Kingdom). The researchers came to the conclusion that one of the 6 examined samples showed an abnormal alveolar structure in agreement with "focal centriacinar/lobular emphysema." The specimens were extracted from 3 canopic jars, one canopic coffin and 2 bundles of embalmed viscera found in the chest cavity [38].

Pneumoanthracosis and Silicosis

Already in the 16th century it had been observed that miners had a short breath and often died of a premature death, which could be traced back to the inhalation of the dust during work [39]. Describing the effect of the environment of mine workers, Bernardino Ramazzini (1633–1714) wrote in 1705: "Thus far I have given an Account of such workmen as are thrown into various diseases by the Malignity of the Minerals and Fossils that they handle and use in the way of their business" [as quoted in 40]. This was followed by the first use of the term "pneumoconiosis" by Zenker [41] (1825–1898) in 1867. In the field of palaeopathology it was Ruffer [42] who noted the presence of signs of diffuse anthracosis in the lungs of a 20th-dynasty mummy. He discovered "jet black or dark yellow material" in alveolar spaces and interstitia reaching deep into the tissue with the only possible diagnosis of anthracosis. The reason for this was related to the use of indoor fire and professions involving working in dust- and smoke-rich air. Whether the continuous exposure to small air-floating particles could have had an impact on life condition in Ancient Egypt, thus enhancing the probability of other lung diseases or whether it occurred naturally asymptomatically, is subject to further discussion. In 1940, Shaw [34] noticed anthracosis in the 3,500-year-old Egyptian mummy next to severe emphysema and bronchopneumonia. Especially the interlobular septa of the upper and lower lobes of the right lung found in the canopic coffin were affected, yet not the middle lobe which was marked with emphysematous bullae. A closer look revealed many black masses next to the bronchi and their bifurcation, leaving no doubt that those were macroscopically visible anthracotic lymph nodes. Few decades later, Reyman et al. [11] discovered anthracotic pigment during the autopsy of Nakht (ROM I) notably in the connective tissue of the lung. They even found "bright birefringent particles," which they thought to be silica, but after using X-ray diffraction analysis and electron microscopy, they regarded them as granite particles. The first description of sand silicosis in Ancient Egyptian remains, however, is to be found in Cockburn et al. [10] and Tapp et al. [43] work. Sand pneumoconiosis is mentioned

during the autopsy of PUM II (Pennsylvania University Museum), a mummy of unknown age and origin, belonging to an individual believed to have deceased at the age of 35–40 years. The embalmed viscera were divided into 4 packages but only one contained abdominal organs such as the spleen and parts of the intestines, while all the other 3 contained lung tissue. After rehydration and staining the lung tissue, bronchioles, bronchi, cartilage and connective tissue were observed. The cellular structure was partially lost and replaced by nodular or diffuse fibrosis. Throughout the fibrotic areas, anthracotic pigment deposits and silica particles were shown to be predominant: sand pneumoconiosis is indeed the main source for fibrotic change. Whether it caused symptoms or not was impossible to confidently state, but it supported the hypotheses of inhaling sand during desert storms leading to air pollution. Similarly, Tapp et al. [43] investigated the corpse of a mummy called Nekht-ankh (12th Dynasty, Middle Kingdom, ca. 1800 BC). This palaeopathological approach was conducted in the context of the well-known interdisciplinary *"Manchester Mummy Project,"* where a catalogue of histological, radiological and macroscopically findings of different mummies was generated [5]. The content of the jars next to the mummy was examined and analyzed: parts of lung tissue in one of them were found. Although the mummy itself was in bad condition, the extracted organ was well preserved and yielded new information on fine particles, especially in fibrotic areas and lymphatic tissue around the blood vessels. Ventura et al. (2005) identified human tissue from 4 canopic jars from one individual, and in 2 of 4 samples, they found histological evidence of lung tissue containing deposits of anthracotic pigment and silica crystals [44].

Pulmonary Tuberculosis

The earliest references to tuberculosis date back to 1900 BC in Babylonian and to 1500 BC in Indian texts. Later, in the days of Hippocrates, the terms "phthisis" or "consumption" were used. A few centuries later, Girolamo Fracastoro (1478–1553) mentioned an invisible "virus" causing the disease. The characteristic lesions were named "tubercles" by Sylvius de la Boë of Amsterdam (1617–1655). Throughout the following centuries, various famous physicians tried to elucidate the physiopathology of this disease, but the first appearance of the term "tuberculosis" itself was made in 1834 by the German physician Johann Lukas Schönlein of Würzburg (1793–1864) [45]. One of the first descriptions of tuberculosis by A.J.E. Cave in 1939 dealt with anatomical characteristics of mummified bodies and focused on skeletal anomalies [46]. Ruffer and Smith described a case of extrapulmonary tuberculosis in a 3,000-year-old mummy, but microscopic proof of bacteria could not be adduced [47]. In 1979, Zimmerman unquestionably detected bacteria in bone tissue stained with the Ziehl-Neelsen solution. He also examined lung tissue from the same mummy, a 5 year-old child dating from the beginning of Christian era in Upper Egypt (Coptic 3rd–7th cent. AD) but could not detect any bacilli that would have definitely proved the occurrence of acute primary tuberculosis [48]. Nerlich and colleagues at last were able at last to show molecular evidence by investigating lung specimens of a mummy dating to the New Kingdom (1550–1080 BC) using Polymerase chain reaction (PCR) [49]. Donoghue et al. investigated lung tissue specimens from Dr. Granville's mummy (600 BC), but the organs were still in situ and not extracted or embalmed. Nonetheless, histological and aDNA analysis were performed showing clear signs of *Mycobacterium tuberculosis* activity, hence confirming the coexistence of the pathogen and its host a millennia ago [50].

Digestive System (Liver and Gallbladder)

Chronic Cholecystitis and Cholelithiasis

Hippocrates and Aristotle (384–322 BC) had knowledge of biliary diseases, but it was the later Greek physician and pioneer in the medical sciences in antiquity [51], Alexander of Tralles (525–605 AD), who made the first accurate description of cholelithiasis in humans relating it to the obstruction of the liver. Gentile da Foligno (1272–1348) mentioned secondary inflammation of the gall bladder due to the obstruction of the cystic duct by a gallstone for the first time in the 14th century [52]. However, Shaw [35] examined the liver and also the gallbladder, which was still caudally attached to the liver. The 2.0 cm long bladder and 0.1 cm thick wall seem to be normal but through microscopic examination Shaw took notice of Rokitansky-Aschoff sinuses, a sinking of the mucosal surface reaching into the muscular layer causing no damage but believed to be associated with chronic cholecystitis. The reason causing the morphology of Rokitansky-Aschoff sinuses is a hyperplasia of epithelial cells and subsequent herniation through the fibro-muscular layer. Such findings can present asymptomatically in healthy patients too. Concerning diseases of the gallbladder in ancient preserved bodies, the literature research did not yield further information about Egyptian mummies on this matter, but some data could be found about pre-Columbian Chileans in a publication by Munizaga et al. [53]. During the examination of the gallbladder of Har-mose simulta-

neously occurring morphological signs such as fibrosis of the wall, hyperaemia, oedema, inflammatory infiltration with lymphocytes, plasma cells and granulocytes were not described, yet they would be specific for histopathological evidence of cholecystitis. These signs were absent due to the shrinkage of the soft parts during mummification, and therefore, they were not visible. More than a decade before Shaw, Smith and Dawson mentioned multiple gallstones in a 21st Dynasty mummy with a thin-walled gallbladder, not supporting the idea of chronic cholecystitis [54].

Liver Fibrosis and Cirrhosis

The term "cirrhosis" was coined by René Laënnec originating from the Greek "kirrhos" meaning "tawny yellow" [55]. As Ruffer had already predicted in 1910, liver fibrosis and cirrhosis would be shown in the future due to his new histological approaches [56]. For example, in the case of ROM I, a teenage individual who died of splenic rupture, on whom Reyman et al. [11] performed histological examination, indistinct hepatic parenchyma but clear fibrous patterns typically for liver fibrosis already advancing to the stage of early cirrhosis were identified. The fact that a young individual was affected by cirrhosis leads to the only explanation of schistosomal-caused portal hypertension. This was supported by the findings of an infestation of the liver and intestines with calcified *Schistosoma* eggs (cf. Results -1b). It is believed that the cirrhosis led to pre-hepatic hypertension and subsequently to spleen enlargement and ended up in the rupture of the spleen, which seemed to be the cause of death of ROM I [11, 57].

Cardiovascular System

The only case of cardiovascular disease inferred from the study of canopic jars is the recent investigation by Bianucci et al. [58] involving radiological, histological and genetic examination of tissue specimens found in canopic jars of a 3,500-year-old Egyptian mummy. The analysis shows pulmonary oedema and bleeding ascribable to acute decompensation of a chronic left heart failure, which ultimately led to the individual's death. It is believed chronic hypertension may have been the cause of the failure. More knowledge on the palaeopathology of the cardiovascular system in Ancient Egypt derives from the study of mummies. The heart was usually left in situ as, according their system of belief, it would be weighted against the feather of truth in the afterlife. Pathological changes of major arterial vessels have been identified in the form atherosclerosis in several élite mummies. Initially, a histological examination of the vascular tissue, as that implemented by Sir Marc A. Ruffer allowed for a certain diagnosis: among the main findings is, for example, the demonstration of severe atherosclerosis in the aorta of Pharaoh Merenptah (19th Dynasty), while Shaw demonstrated pathological changes in the superior mesenteric artery of the 18th-Dynasty singer, Har-mose [59]. Such invasive studies have been substituted in more recent times by CT examination, culminating in the Horus Study, which showed the presence of atherosclerotic changes in 20 of 52 analyzed Ancient Egyptian mummies [60]. While a certain methodological debate exists on the accuracy of such radiological finding with suggestions of the necessity to use micro-CT or old-style histology [61, 62], the existence and distribution in the upper crust of atherosclerosis in Ancient Egypt have been clarified. Data confirms the information derived from artistic and literary evidence [63].

Discussion

It can be seen that canopic jars are not only Egyptologically but also medically important. A recent publication by Sheikoleslami and Ikram, a multidisciplinary study of mummies and their corresponding canopic jars (including Egyptology and radiology) from the 22nd and 25th Dynasties, has once more underlined the necessity of a holistic approach when assessing this rather peculiar bioarchaeological material [64].

Canopic jars are filled with viscera such as liver, lungs, stomach and intestines, which can all be affected by various diseases. While diseases of bones, skin and muscle can be verified in mummies, the large number of collected results and observations clearly speak in favour of the unique scientific opportunity represented by canopics jars, namely, to study the primary visceral target for many a pathogen or condition. The growing impact of canopic jars is supported by an increasing number of publications on this topic in recent years. Arguably, it is also important to determine whether the canopic jars and their contents really belong to the mummy buried alongside them in order to clarify the true health status of the corresponding individual. This analysis shows that there are more studies on lungs, liver and intestines available than on stomach tissue. The reasons remain unclear but could be due to the rapid decomposition of stomach tissue; therefore, it could be more difficult to identify the relevant gastric structures. As Grove and colleagues observed in their approach to the systematical analysis of soft tissue histopathology in palaeopathology, the brain and the kidney

have poor conservation potential and are more difficult to identify due to the lack of connective tissue and absence of certain "key structures," which is instead the case of lung and liver tissues [65].

The comparison of various studies showed that the examined tissue is not always in the same condition leading to a decrease of visible structures. In some samples, even cellular structures like hepatocytes were visible, whereas in other studies, this cellular level has not been reached because of different levels of preservation [28]. The identification of diseases and sequencing of pathogens can lead to a better understanding of the co-evolution of their hosts and their impact on ancient civilisations. In this case, molecular analysis acts as an enhanced diagnosis that does not depends on full histological preservation. Metagenomics techniques can, in a single run, characterize the genetic material of the host and also of every pathogen present in the sample at the moment of death. Both advantages would be useful for canopic jar analysis, potentially relating organs from the same individual, thanks to genetic profiling, but also in order to screen genetic disorders and pathogens, and even more ambitiously, reconstruct whole microbial communities that live in our body, or microbiome, known to be intimately related with abdomen, neural, inflammatory and immune conditions [66–69]. Some applied examples: in a confirmation study performed by Shin et al. [70] on a 17th century AD Korean Mummy diagnosed with atherosclerotic cardiovascular disease, several risk alleles related with the condition were found, indicating genetic predisposition of the disease. A similar study, this time with tuberculosis, in a Hungarian Mummy led to characterize 2 different strains of *Mycobacterium tuberculosis* in the same individual who was diagnosed with a cachectic syndrome [71]. Conversely, the above-mentioned case of Bianucci et al. [58], studying a canopic jar, did not reveal the presence of *M. tuberculosis*, excluding what would otherwise be an erroneous TB diagnose.

On a different track, focusing on the microbiome, various studies were successful in reconstructing microbial communities in South American Mummies [72, 73]; much more well-known is Ötzi's (i.e., the Tyrolean Ice Man) gut microbiome retrieved from colon and stomach content and whole-genome reconstruction of *Helicobacter pylori* [74, 75]. All of these studies prove that genetic-derived disease, pathogen presence and microbiomes can be inferred from mummified soft tissues – including canopic jars, when DNA preservation is sufficient.

Furthermore, answers to dynasty-specific clusters of disease indicating the nature of an epidemic or how infectious diseases emerged in Ancient Egypt can be found.

Conclusion

For the above-listed reasons, the possibility to shift the main focus of paleopathological research to canopic jars and mummified viscera may prove a turning point in the history of bioarchaeology and retrospective medical diagnostics. While until now most studies have concentrated on single cases or single canopic jars, an approach targeting large series of canopic jars, combining Egyptological analysis and biomedical research, is thus suggested as most valuable to determine the antiquity and evolution of diseases, which still affect mankind [76].

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Disclosure Statement

The authors declare that they have no conflicts of interest.

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